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AD-A204 048 REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 89-0004
6a. NAME OF PERFORMING ORGANIZATION: Massachusetts Inst of Technology; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NA
6c. ADDRESS (City, State, and ZIP Code): Plasma Fusion Center Cambridge, Massachusetts 02139	7b. ADDRESS (City, State, and ZIP Code): Building 410, Bolling AFB DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AFOSR/NA; 8b. OFFICE SYMBOL (If applicable): NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: AFOSR-87-0096
8c. ADDRESS (City, State, and ZIP Code): Building 410, Bolling AFB DC 20332-6448	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2308; TASK NO. A1; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification) (U) Experimental Study of a Hybrid Plume Plasma Rocket

12. PERSONAL AUTHOR(S) F. R. Chang-Diaz and T. F. Yang

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 11/15/86 TO 6/30/88	December 30, 1988	

16. SUPPLEMENTARY NOTATION

Direct current,

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	DC-power, Microwave, tandem mirror (mpm)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The components for a tandem mirror plasma source to be used as a plasma propulsion experimental facility have been made. The device has been assembled and is ready for operation.

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☒ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr Mitat Birkan	22b. TELEPHONE (Include Area Code): (202) 767-4937; 22c. OFFICE SYMBOL: AFOSR/NA

DD Form 1473, JUN 86 — Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

PLASMA FUSION CENTER

AFOSR-TR- 89-0004

Final Technical Report

for the period

November 15, 1986 – June 30, 1988

CAMBRIDGE, MASSACHUSETTS 02139

ASSOCIATED WITH
DEPARTMENT OF ELECTRICAL ENGINEERING
AND COMPUTER SCIENCE
DEPARTMENT OF MATERIALS SCIENCE
AND ENGINEERING
DEPARTMENT OF MECHANICAL ENGINEERING
DEPARTMENT OF NUCLEAR ENGINEERING
DEPARTMENT OF PHYSICS
FRANCIS BITTER NATIONAL MAGNET LABORATORY
RESEARCH LABORATORY OF ELECTRONICS

89 2 10 095

Final Technical Report

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November 15, 1986 – June 30, 1988

F. R. Chang-Díaz*

T. F. Yang

MIT Plasma Fusion Center

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AFOSR Grant #87-0096

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*Astronaut Office of the Johnson Space Center, Houston, TX.

Abstract

The components for a tandem mirror plasma source to be used as a plasma propulsion experimental facility have been made. The device has been assembled and is ready for operation.

1.0 Purpose

The purpose of this work is to construct a tandem mirror device to be used as a high temperature plasma source for hybrid plume plasma rocket experiment.

A hybrid plume is one where the exhaust fluid is a stratified mixture of hot plasma and neutral gas in a magnetic field. The macroscopic properties near the wall boundary (i.e., temperature, density, fluid velocity, thrust, etc.) exhibit a drastic radial variation over small distances. The exhaust is extremely hot in the core and relatively cold near the edge.

Such a hybrid plume can be produced by surrounding the hot plasma exhausted from the end of a tandem mirror magnetic confinement device with an annular hypersonic, coaxial gas jet. The resulting plasma-gas structure has useful applications in high power, variable I_{sp} rocket propulsion.

2.0 Accomplishments

With the funding of the Air Force Instrumentation Program the components for the basic tandem mirror, i.e., eight central cell coils, four mirror coils and four booster coils, a vacuum chamber and support structure, were designed and built based on the concept developed over the past year [1–4]. Figure 1 shows the completed assembly of the device mounted on a stand. On the left end is the vacuum pumping system and there is an identical system on the right end. In front of the device there is the laser fluorescence diagnostic system. There are two power supplies for magnetic coils and a 2 kW, 2.4 GHz microwave transmitter on the other side of the device. This equipment was obtained

from other groups in the Plasma Fusion Center. The successful completion of the device construction and the initial testing operation were made possible with complementary funding from NASA through J.P.L. and the technical support of the M.I.T. Plasma Fusion Center.

The engineering design of the device is shown in Figure 2. Figures 3 and 4 show the central cell coil and the coils enclosed with liquid nitrogen casings. Because of the budget constraint the vacuum thermal insulation jacket was not provided for the central cell coils at the present time. Figures 5 through 8 illustrate the construction sequence of the mirror coils, liquid nitrogen casings and vacuum jacket. The vacuum jacket is an integrated part of the vacuum chamber. Cooling and vacuum jacket were not provided for the booster coils also due to the constraints of the budget. The coils and vacuum jacket were fabricated by outside manufacturers and assembled by us. Each coil and its casing are separated by special springs which are visible in Figures 6 and 8. The springs are our own invention. They are designed in such a way for space saving and cost reduction. Each spring must be able to resist both the thermal and magnetic stresses involved. At the same time the heat conduction through the springs must be minimized and the springs are electrically isolated from the coils. Therefore, assembly was a slow and difficult process. The coil had to be tested electrically and the casing checked for vacuum lightness at every step. Figure 9 shows the waveforms of the electrical test made. Since the vacuum chamber is made of nine sections and has twenty-four parts, the vacuum integrity was a major concern. With the strict observation of high standards of vacuum preparation techniques and repeated testing of the vacuum tightness and cleaning, the chamber was pumped down to a pressure 10^{-6} Torr in one day. Now the chamber is constantly operated at a high vacuum of 10^{-8} Torr.

3.0 Initial Testing Operation

In order to carry out testing and calibration, the magnetic field coils were energized to 10% of the designed field strength and were run in this manner at steady state operation. Verification of the design configuration and value was achieved by mapping and analyzing the magnetic field profile using a Hall probe.

Much time has been expended in learning to inject the microwave power into the chamber and creating a plasma breakdown. Since the port size is limited, we were forced to use the coaxial cable and antenna as the means to transmit and inject the microwave power. The field at the point of injection was below resonance due to the voltage limitations of the DC power supply used. Little technical data is available for the old surplus microwave unit. After a month of trial and error, we gradually shielded out the rf power leakage and tuned the magnetic power supplies to their limit to reach resonance field. The first discharge was finally initiated in mid-August. Figures 10 and 11 are plasma discharge viewed through the end port and side port.

Presently the machine is a turnkey operation. The power supply, the gas feed, and the microwave injection are all operated manually. Only time will permit it to become an automated operation. In the meantime, all results that may be obtained from the machine, even in the turnkey mode, will be extremely useful. Discharges at wide ranges of gas pressure, from 1 to 150 mtorr, and at various power levels have been reached. It is necessary to measure the power level with proper instrumentation that must still be acquired.

References

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[2] Chang, F.R., W. A. Krueger, T. F. Yang, AIAA/DBLR/JSASS International Electric Propulsion Conference, paper AIAA-85-2049, Alexandria, VA, Sept. 1985.

[3] Chang, F. R., W. A. Krueger, T. F. Yang, J. L. Fisher, "Plasma-Gas Interaction Study in a Hybrid Plume Plasma Rocket," AFOSR/AFRPL Chemical Rocket Research Meeting, paper 51, Lancaster, CA, March 1985.

[4] Yang, T.F., R.H. Miller, K.W. Wenzel and W.A. Krueger, AIAA/DBLR/JSASS International Electric Propulsion conference, paper AIAA-85-2054, Alexandria, VA, Sept. 1985.

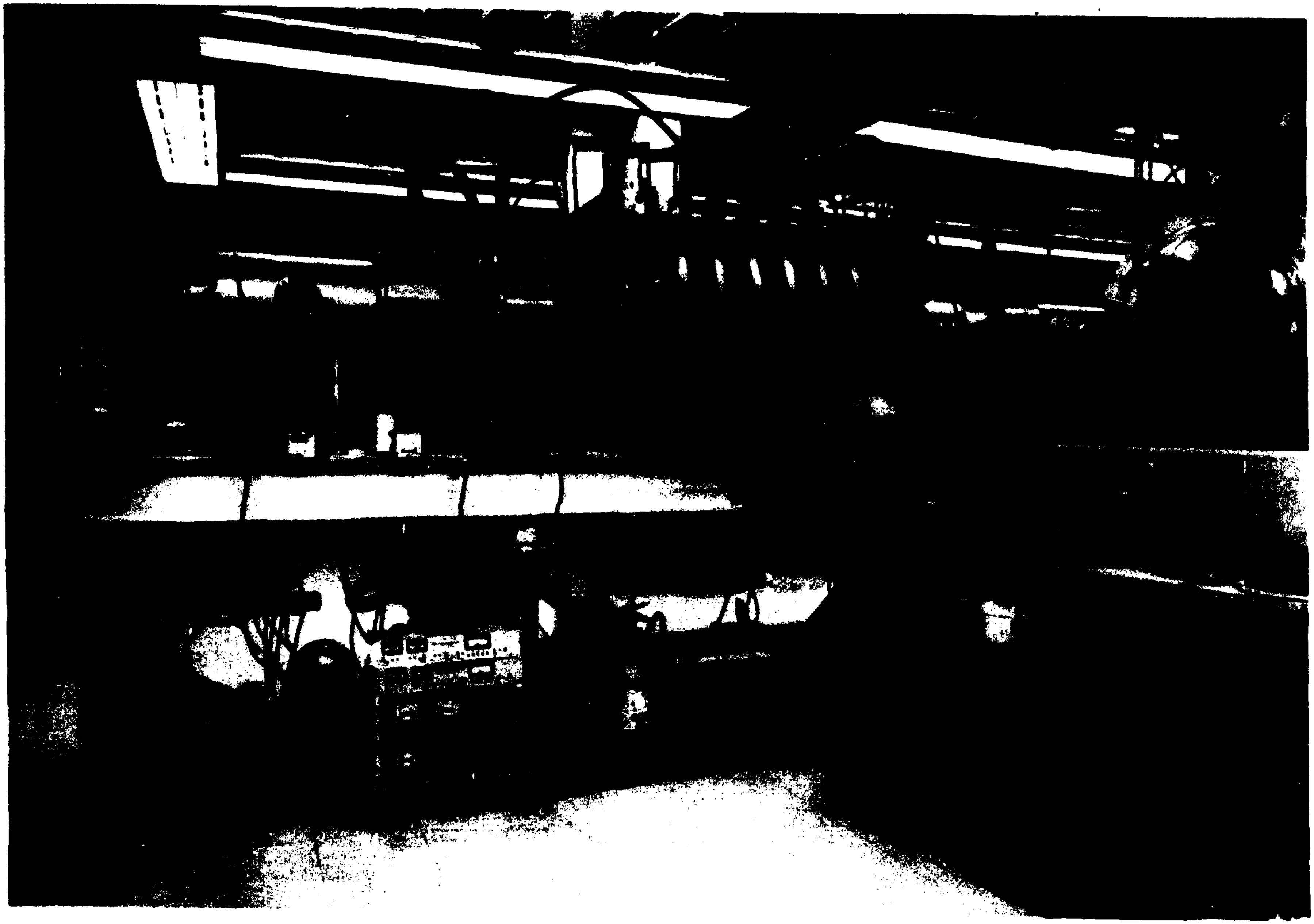


Fig. 1. Photograph of the tandem mirror plasma source assembly.

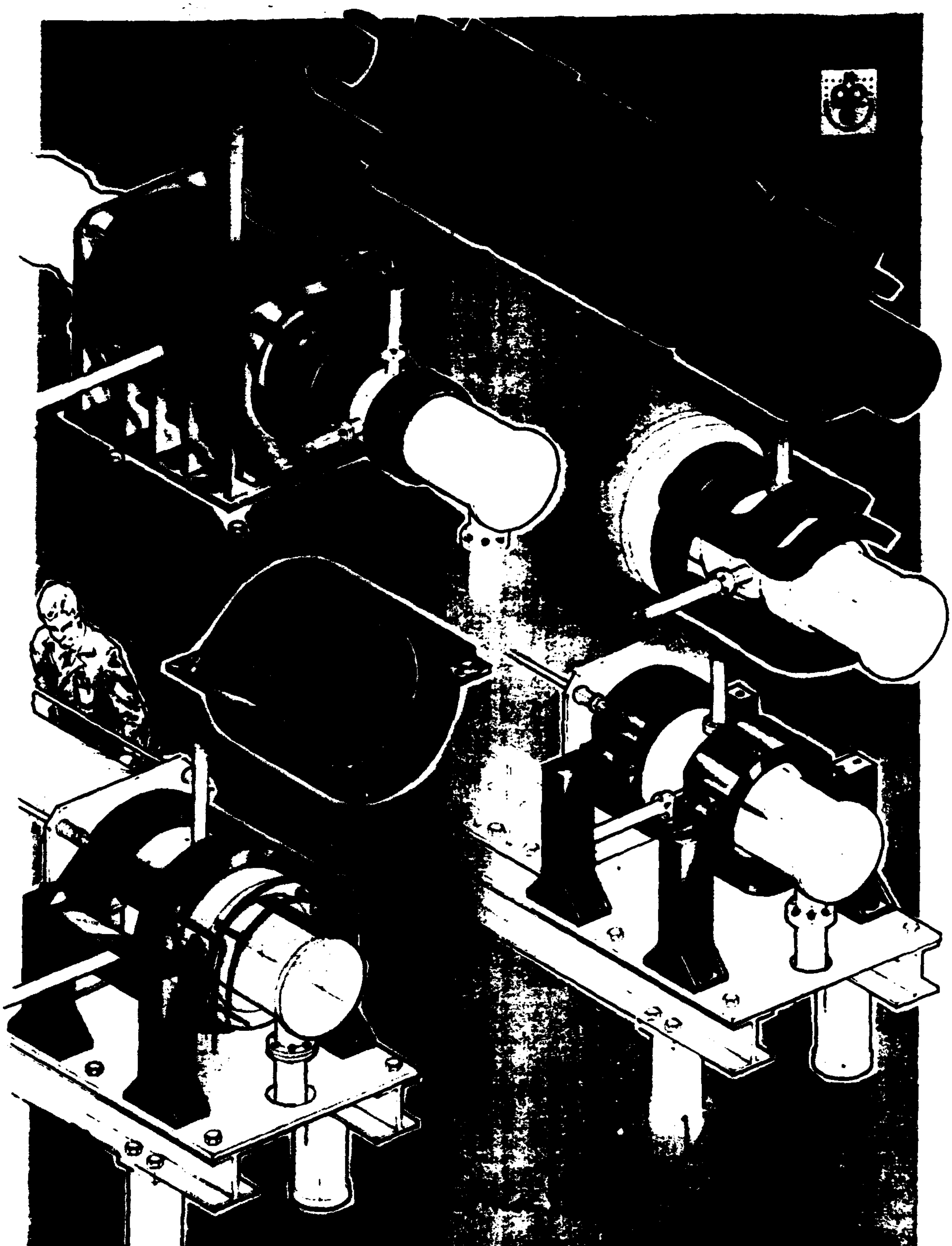


Fig. 2. Engineering design of the tandem mirror plasma device.

Fig. 3. Central cell coil.

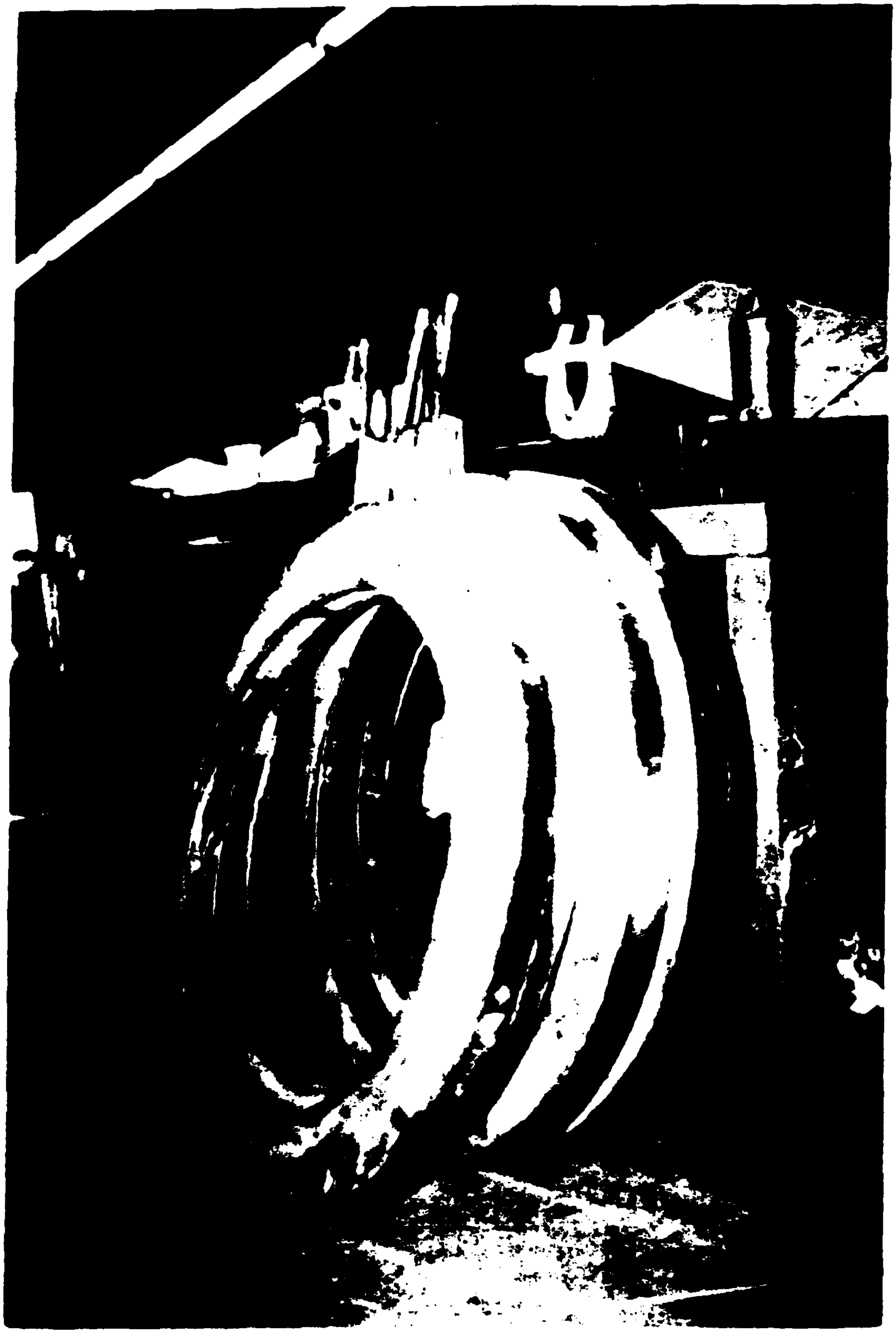


Fig. 4. Central cell coils enclosed by liquid nitrogen casings.

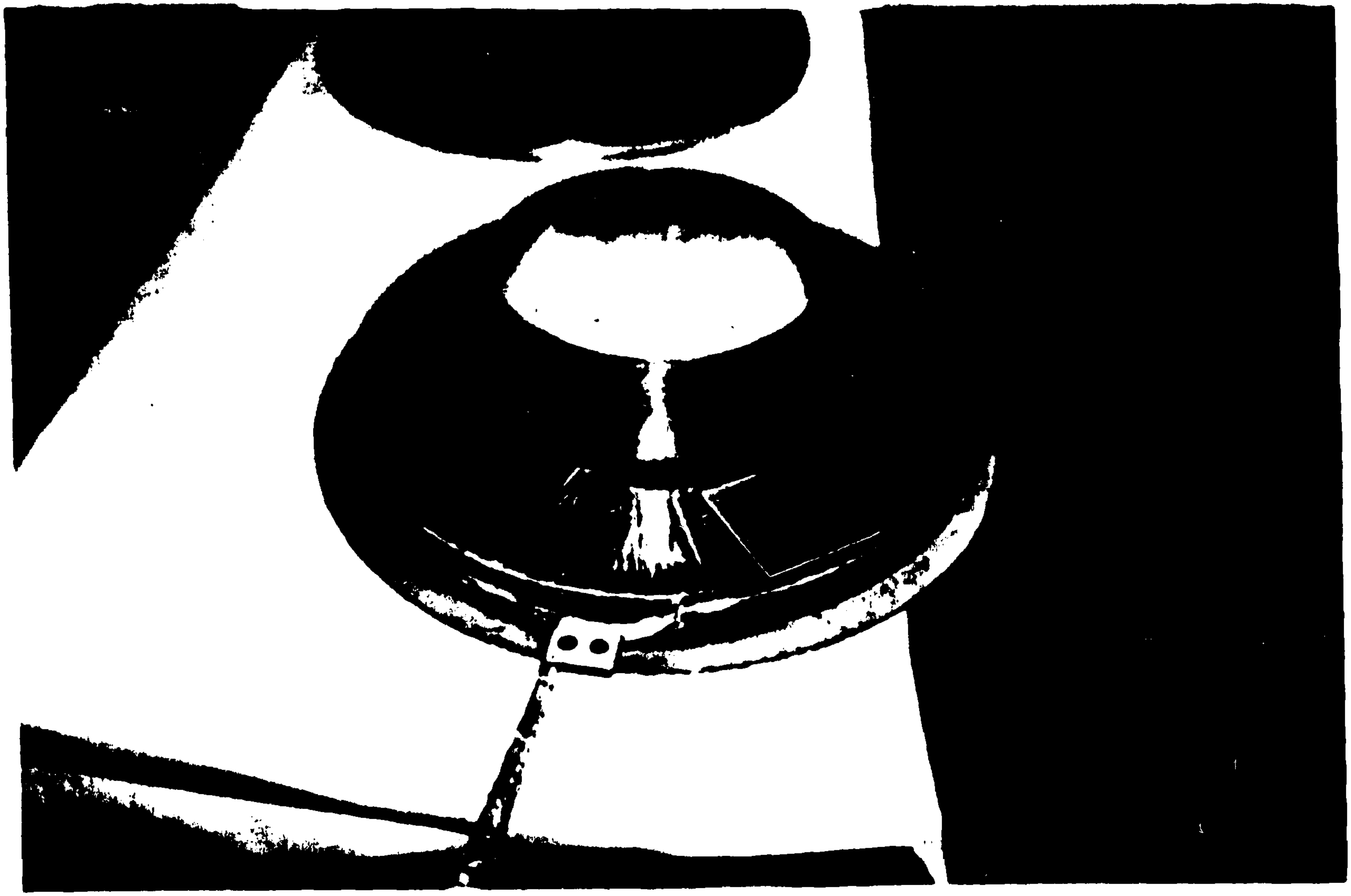


Fig. 5. One of the three pancakes of the mirror coils.

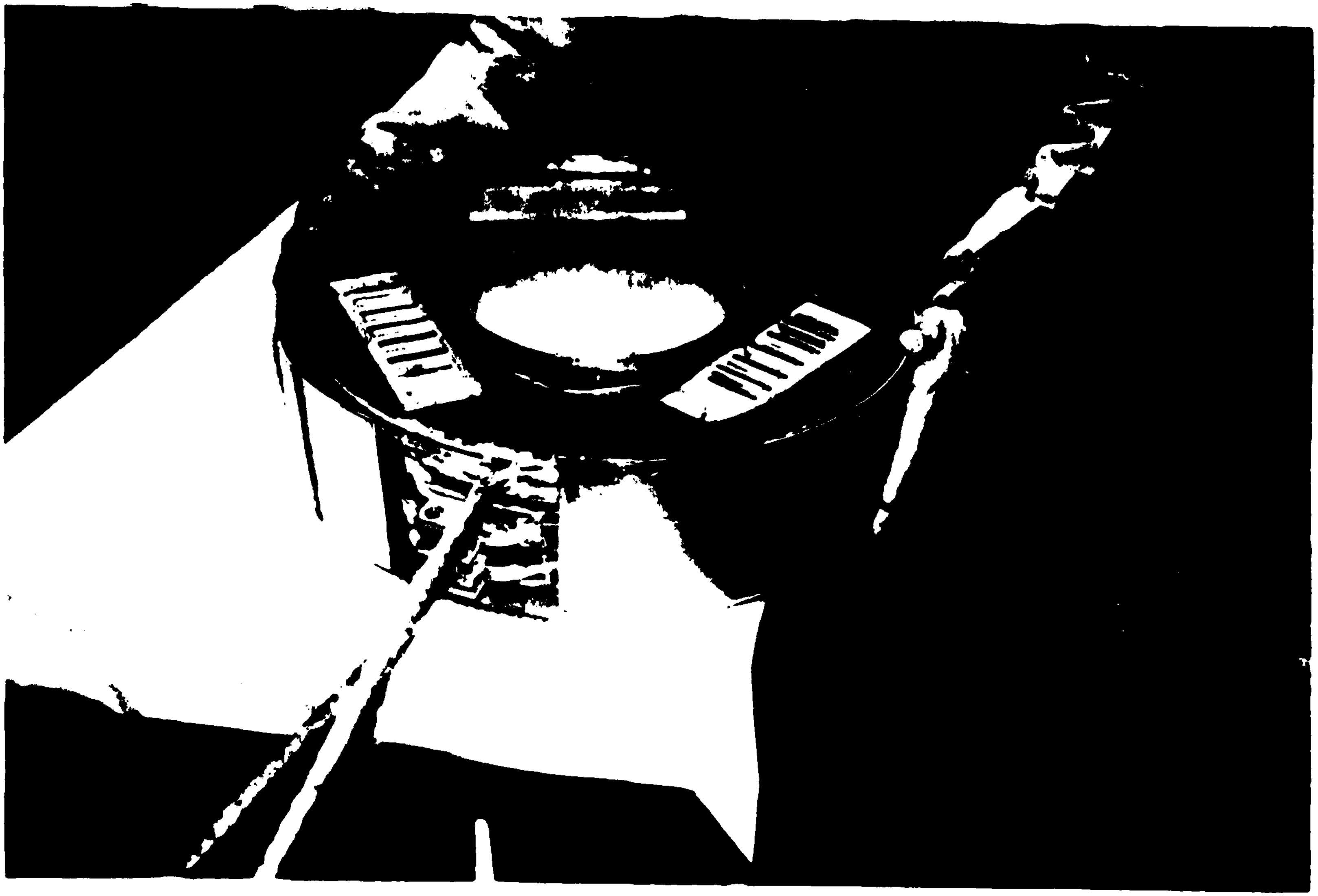


Fig. 6. Stack of three pancakes with springs and insulators.

Fig. 7. Mounting of side wall and top cover.

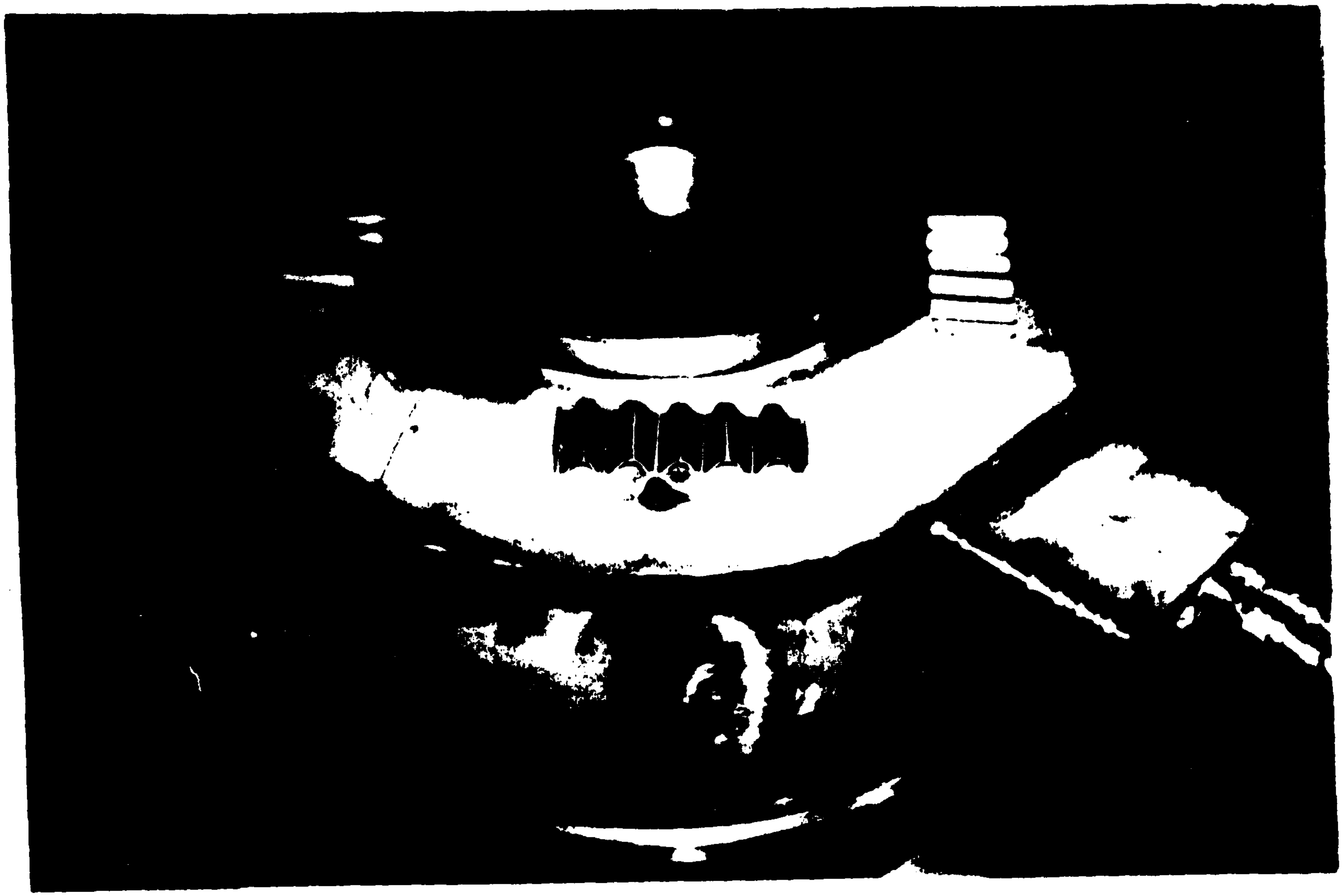
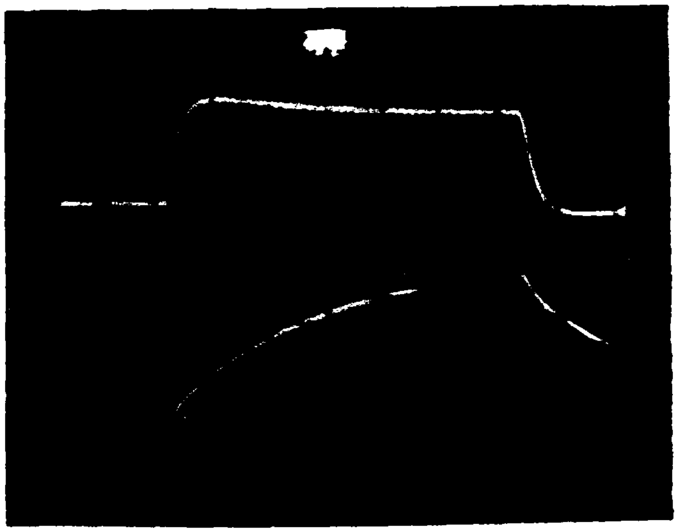
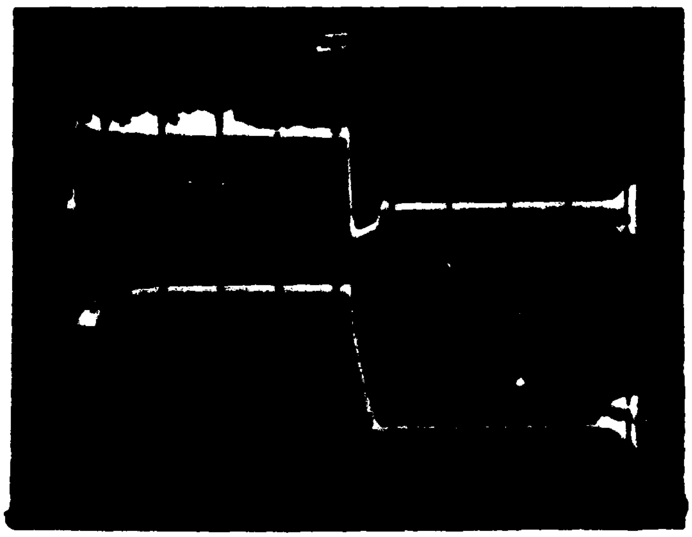


Fig. 8. Completed liquid nitrogen casing with springs.

Fig. 9. Current and voltage waveforms of the electrical test of the coils.



5 volts
220 amps
1 sec



2 volts
82 amps
1 sec

Inductance: 3 mh
Resistance (room temp): 3 m ohm

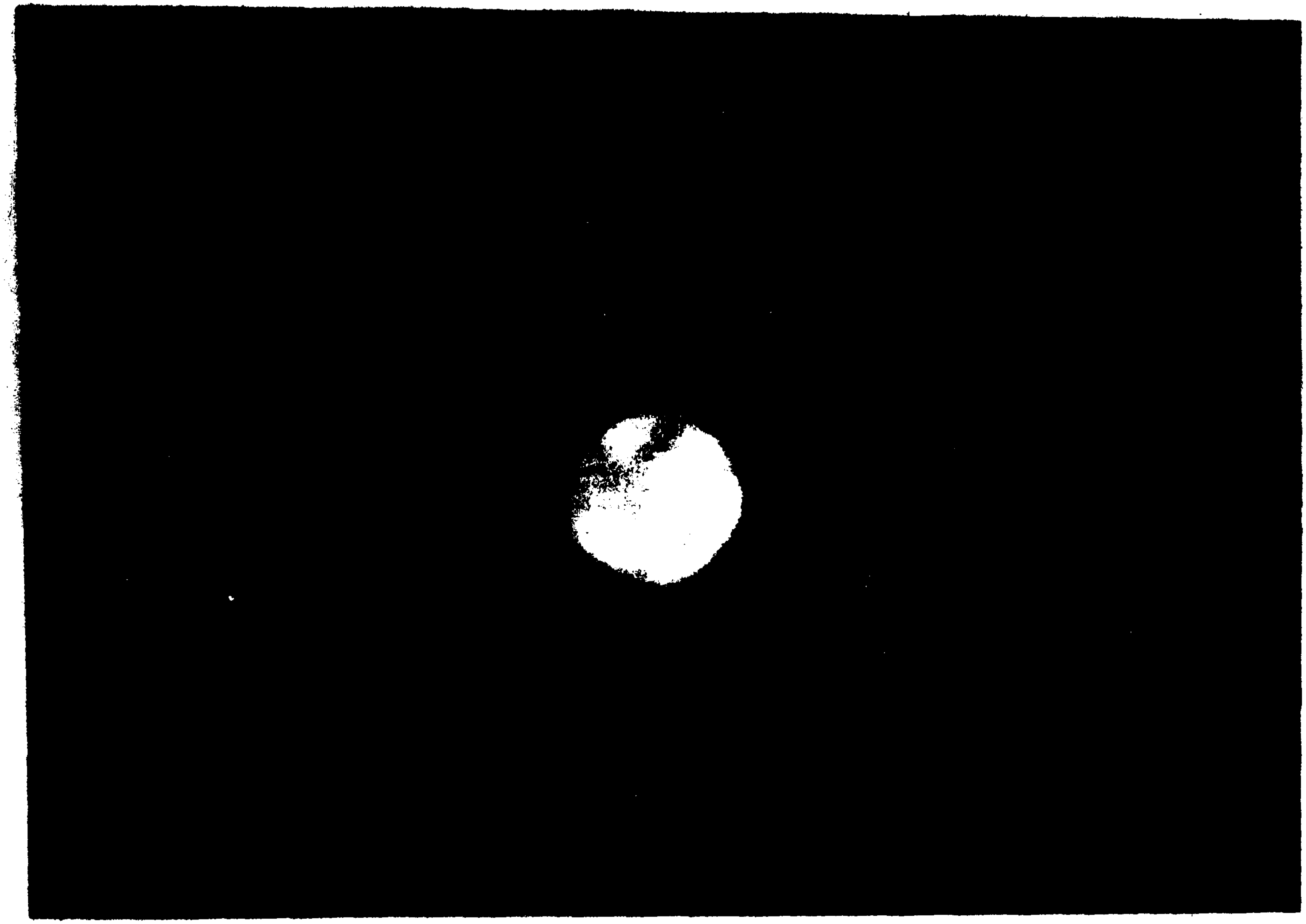


Fig. 10. Microwave plasma discharge viewed through the end port.

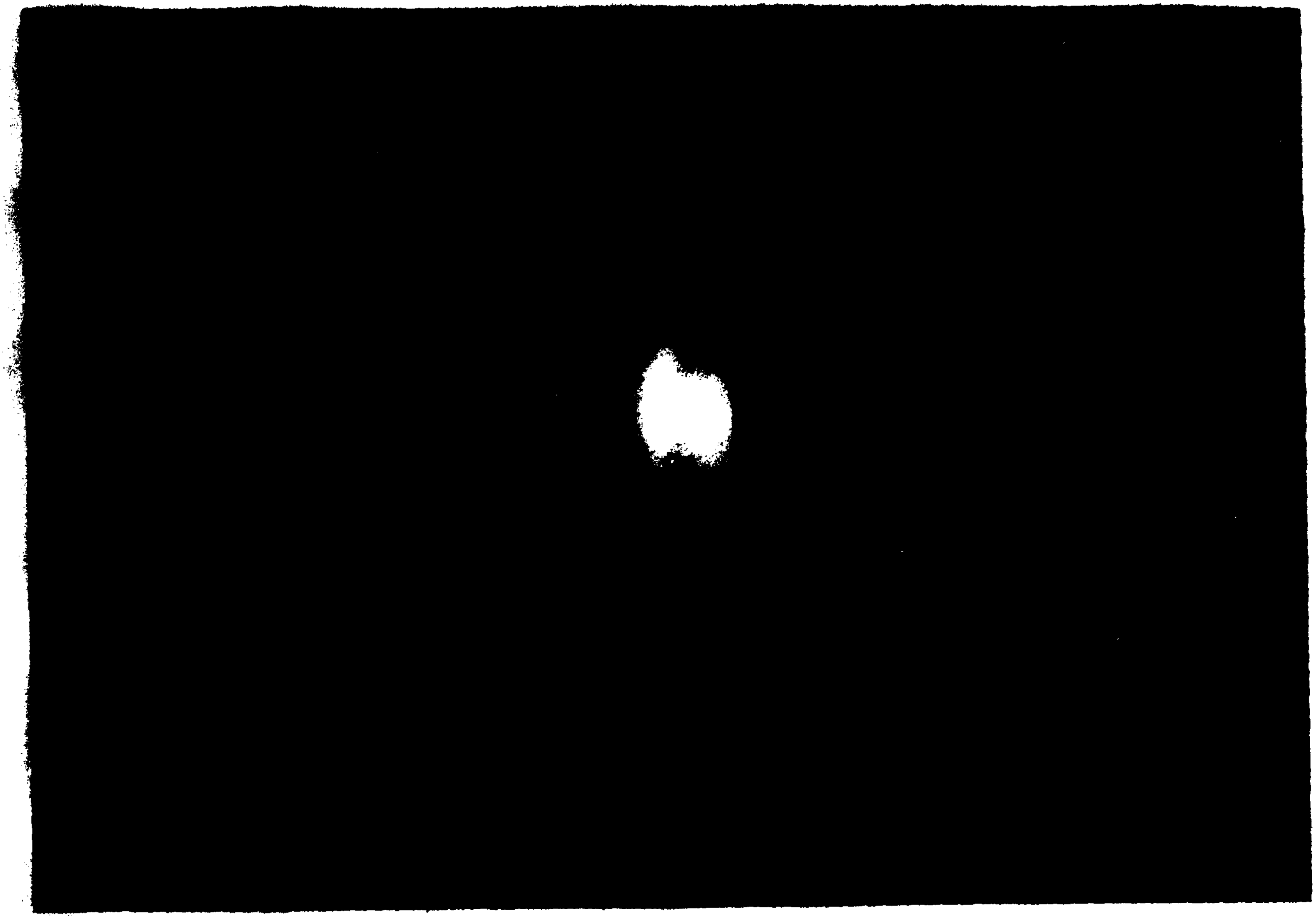


Fig. 11. Microwave plasma discharge viewed through the side port.